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TECHNICAL MEMORANDUM 1564

FEASIBILITY STUDY FOR THE DEVELOPMENT OF A SMOKE TRACER FOR AN APDS SHOT

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JULY 1965

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DA PROJECT 1C523801A296

PICATINNY ARSENAL
DOVER, NEW JERSEY

FEASIBILITY STUDY FOR THE DEVELOPMENT OF A SMOKE TRACER FOR AN APDS SHOT

by

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Department of the Army Project 1C523801A296

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OBJECT

To develop a smoke tracer for incorporation in the nose cone body of a hypervelocity, fin-stabilized, armor-piercing round to mark the round trajectory. The experimental round employed was the 90/40 mm T320E6 arrow projectile

SUMMARY

A feasibility study of a smoke or vapor stream system to function in the nose cone of a fin-stabilized round was conducted. The conventional base-located system could not be used because (a) the round contained a discarding sabot mechanism, and (b) the vibration, jolt, and dust following the discharge of the large vehicle-mounted gun would cause the gunner to momentarily lose sight of the missile. Hence, a persistent trail observable by daylight was needed.

Titanium tetrachloride was tried because, on exposure to air, it forms dense white clouds of titanium hydroxide. However, the corrosive properties of this material made it difficult to package. Since calculations indicated that nose temperatures exceeding 300°C would be attained during projectile flight, a new approach using a heat-sensitive chemical nose fuze was formulated. Diazodinitrophenol (DDNP), which ignites after 0.25 second of flight (200°C), was pressed into the nose cone tip assembly. A conically shaped red smoke composition was inserted directly behind the DDNP. Two holes drilled near the apex of the cone body allowed the generated smoke to escape. This approach worked satisfactorily in static tests. In ballistic tests, however, the smoke composition was ejected as a puff of red smoke with no streaming. The chemical nose fuze proved successful in all tests and a patent application based on this new and novel concept has been accepted and forwarded to the U. S. Patent Office.

INTRODUCTION

The possibility of using titanium tetrachloride was based both on its own good smoke forming properties and on certain characteristics of the round. With a 0.060-inch orifice in the apex of the tip assembly an internal pressure of 390 psi can be generated at the velocities achieved during flight. This pressure is in excess of what would be needed to force the titanium tetrachloride out of the base orifices during flight after setback forces had ruptured its container.

Two immediate problems arose with this approach. First, a suitable plastic that could be fabricated into a cone-shaped container with a wall thickness of 0.001 to 0.002 inch (to allow for maximum internal volume) had to be found. Titanium tetrachloride attacked polyethylene, especially in the presence of moisture, but it was compatible with saran, mylar, and teflon. Heat sealing these materials with the corrosive liquid in place constituted a problem. These difficulties in packaging, along with the consideration of keeping the exit orifices from becoming blocked by the plastic sheeting, warranted a new approach to the development of a tracer system.

No particular smoke color or density was stipulated. However, a 0.25-second delay and a 1.25-second burning time were required. Red smoke compositions were chosen for tracer evaluations because of their good performance characteristics and controllable burning rates in consolidated smoke systems. Smoke cones were first prepared by pouring a slurry of the composition into paper cones and allowing them to dry. In later experiments, pressed smoke compositions were used to counteract setback forces and achieve in addition a more controllable smoke.

Simultaneously, studies were conducted towards the development of an initiator that could be ignited by aerodynamic heat transfer during ballistic flight. Heat transfer studies indicated that a copper tip could attain a temperature in flight sufficient to propagate an initiator if its ignition temperature was approximately 300°C. An experimental determination indicated that M1A1 squib composition consisting of 20/60/15/5 diazodinitrophenol/potassium chlorate/charcoal/nitrostarch has a one-second ignition temperature value at approximately 326°C. During both static and ballistic testing, this composition worked satisfactorily. A literature search revealed, however, that diazodinitrophenol, one of the ingredients in the M1A1 composition, has a one-second ignition temperature value at approximately 200°C. It was therefore decided that diazodinitrophenol would be used exclusively.

Both static and ballistic tests proved that the entire system functions in proper sequence, but the desired smoke streaming effect was not achieved during ballistic tests.

RESULTS

Figure 1 (p 17) depicts the general configuration of the windshield nose cone body whose interior was designed to carry packaged titanium tetrachloride as the tracer composition. The nose cones used for solid smoke compositions differed only slightly from the diagram shown. The gas exit holes were drilled near the apex just behind the tip assembly, and the sleeve to which the nose cone body was attached had a flat face rather than a pointed one.

Table 1 (p 10) is a compilation of the chemical compositions used as well as their burning rates and ignition temperatures. SR39A is shown to have a fast burning rate of 8.2 seconds per inch compared to 58.0 seconds per inch for SR66A and 23.7 seconds per inch for SR116A. The table also reveals a very low one-second ignition temperature value for SR39A when compared to DDNP.

Figure 2 (p 18) shows the three experimental designs for the tip assembly. Design I had a steel tip with a copper plug for better heat transfer. Designs II and III, later modifications, were made entirely of copper when it was ascertained that this material would not completely melt during flight. The initiating charges were pressed into the tips so that they came into intimate contact with copper.

Figure 3(a) (p 19) depicts the hole configurations used to obtain thermocouple measurements and Figure 3(b) (p 19) shows the furnace, block, and round relationship employed during these measurements.

Table 2 (p 11) lists the results obtained in the first ballistic tests. In all cases, the tip assemblies functioned and ignited the smoke composition which had been inserted into the windshield in paper-molded cones.

Table 3 (p 12) shows the static test results achieved with Design I, II, and III tip assemblies. The tips were affixed to windshields containing SR39A smoke composition in order to subject them to elevated pressures during the performance tests. Ignition was brought about by means of a blow torch directed against the tip.

Table 4 (p 13) is a comparison of burning times achieved for three different smoke compositions when burned in windshields having hole diameters of 0.060, 0.080, and 0.100 inch.

Table 5 (p 14) details the ballistic results achieved with smoke compositions SR39A, SR66A, and SR116A. The white trails obtained were sometimes indistinguishable from the trail obtained when the fins on the round burn in flight. These trails did not persist and were inadequate for tracking.

Table 6 (p 15) lists some of the ignition temperature values for SR66A when puddled directly into the windshield cone. System number 1, which had the largest hole size area, gave good streaming, and system 2, with the smallest hole area, detonated.

Table 7 (p 16) gives the burning characteristics of both SR39A and SR66A when the smokes were pressed into the windshield in three increment steps using rams of different diameters and consolidating at 3 tons dead load.

DISCUSSION OF RESULTS

The use of titanium tetrachloride as a tracer material was suggested because it forms dense white clouds of titanium hydroxide on exposure to moist air. Before packaging titanium tetrachloride, its compatibility with saran and teflon was confirmed and conical bags with a volume of approximately 12 to 14 cc were made from these materials. The bags were loaded with titanium tetrachloride, heat sealed, and positioned in the nose cone body. A cone-shaped metal sleeve with a sharp apex was screwed into the base of the nose cone body so that the bag would be punctured upon setback. It was demonstrated that 390 psi of compressed air applied through a 0.060-inch orifice in the nose of the round could cause puncturing of the bag and force titanium tetrachloride vapors out of two holes (0.020 inch ID) situated in the base of the windshield body (Fig 1). Because of the great difficulty that was encountered in heat sealing the bags after they had been loaded with titanium tetrachloride, efforts were turned toward the development of a solid smoke tracer and an initiator system.

The red smoke SR39A (Table 1) was chosen for the tracer because of its good performance characteristics and rapid burning rate in consolidated smoke systems. The smoke cones prepared for these tests were made by pouring a slurry of SR39A in ethyl alcohol into paper cones and air drying them. These cones (approximate weight, 7 grams) were then inserted into a nose cone with two 0.060-inch holes predrilled in its tip. To simulate aerodynamic heating, a blow torch was played on the tips of the rounds until ignition and propagation occurred. A good smoke display was given in most instances.

Simultaneous studies were conducted towards the development of an initiator that could be ignited by aerodynamic heat transfer generated during ballistic flight. Aerodynamic heat transfer calculations indicated that a steel tip containing a copper plug 0.12 inch long with a 0.05 inch radius would attain a temperature of 300°C in 0.25 second at the velocities predicted for the round (Fig 2, Design I). The first initiating system experimented with was the composition contained in the M1A1 squib (Table 1). When it was found that the most heat-sensitive substance in this composition was diazodinitrophenol (DDNP), whose ignition temperature is approximately 200°C, future experiments utilized this material exclusively, thus eliminating the necessity of preparing a sensitive mixture. Static tests conducted on tip assemblies pressed with 15 mg of DDNP and approximately 70 mg of SR39A showed that DDNP is suitable for directly igniting the smoke composition. Air gun tests subjecting these tip assemblies, which were pressed at 1176 psi, to 56,000 g's indicated that they would withstand setback forces.

For ballistic tests, seven rounds were prepared with SR39A smoke cones. Two different tip radii (0.050 and 0.100 inch) were tested using Design I tip assemblies (Fig 2). These were loaded with either M1A1 composition (15 mg) or DDNP and SR39A as described above. The apex of the windshield contained two 0.020-inch holes. In all the rounds the igniter functioned, with subsequent smoke propagation (Table 2). The smoke, however, emanated all at once in a puff with no subsequent streaming. It was thought that the orifices in the nose cone body were too small and that the pressure buildup was blowing out the copper plugs in the tip assemblies. Indications that this might happen had been noted during earlier static testing (Table 3).

In order to determine whether or not too high a pressure was causing rapid burning and consequent destruction of the tip assembly as well as frequent detonations within the nose cone, changes were made in the composition and design of the item. The tip assemblies were made of copper and the copper plug eliminated when it was determined that aerodynamic friction would not completely melt the tips, and thereby cause deviations during flight (Fig 2, Designs II and III). Different size holes, with diameters 0.060, 0.080, and 0.100 inch, were drilled in the nose cones and two new smoke compositions with slower burning rates (SR66A and SR116A, Table 1) were added to the smokes being tested. The tip assemblies were loaded as shown in Table 3 and were found not to rupture upon testing. Static test results verified that SR66A and SR116A were slower burners and yielded good scarlet smoke displays (Table 4). The table also compares the burning rates with those of SR39A. All static tests indicated that vents of 0.060 inch with the slower burning smokes might produce the desired low pressure and good display characteristics.

For ballistic tests, SR66A and SR116A were puddled into paper cones from an alcohol slurry. A small amount of SR39A was first puddled into the SR66A cone to give initial rapid smoke emission so as to avoid too long a delay time. Table 5 indicates that one round containing the SR39A/SR66A combination did trail but the smoke did not persist (No. 3). Other rounds gave only a faint trail or a puff of red smoke.

A final static test was devised to study the effects of pressure on the burning time. Nose cones were drilled with the hole configurations shown in Figure 3(a), with the dimensions detailed in Table 6, and SR66A composition was puddled directly into them. (In one instance SR39A composition without the aid of DDNP functioned as an initiator for the smoke cone proper.) In this study, thermocouples were placed between the hot block and tip assemblies and within the smoke composition itself to determine the relationship between "skin" temperature and primary ignition (Fig 3(a) and (b)). Admittedly, the design of this experiment was not good because of heat losses to the atmosphere. The fact that streaming occurred from the hole configurations used and that the smoke cone could not ignite before the initiator was the only pertinent information obtained (Table 6). These tests, though limited in number, indicated that the total orifice area was influencing the burning rates. This area could not be increased, however, without weakening the round.

To slow their burning time even further and to protect them against setback forces, smoke compositions SR39A and SR66A were consolidated directly into the nose cones by pressing at 3000 psi using three rams of increasing diameters. SR39A was first loose loaded into the cones to insure fast ignition and a shorter time to first smoke. Consolidation caused slower burning but made the holes in the base nonfunctioning.

Table 7 indicates that pressed SR39A burned less erratically than the poured compositions. For example, when the smoke was emanating from a 0.100-inch orifice, the burning times ranged from 20 to 37 seconds, whereas poured compositions burned in 3.5 and 6.0 seconds (Table 4).

SR66A because of its slower burning characteristics was less erratic in overall performance (Tables 4 and 7) except in one instance when the poured composition burned exceedingly fast (Table 4).

It was concluded that pressed cones containing 13 grams of SR39A, with two 0.100 holes in the nose cone tip and a copper tip assembly containing 15 mg of DDNP and 70 mg of SR39A would have a sufficient burning time, a short enough lag time, and a suitable pressure buildup to warrant ballistic tests.

High speed films as well as visual observation of these ballistic tests at Aberdeen showed that all items ignited in flight but only partial or no smoke streaming occurred. Development of the smoke tracer was terminated at this point and preference was given to an electronic tracking system.

CONCLUSIONS

As a result of this feasibility study, it was demonstrated that heat-sensitive chemical compounds exhibiting low ignition temperatures (200°-326°C) can be initiated by heat originating from the stagnation temperature caused by the ballistic flight of high velocity projectiles. After functioning, these chemical nose fuzes can be used to initiate pyrotechnic material in train behind them. This concept is new and novel, and a patent application covering it has been accepted by Army Materiel Command and forwarded to the U. S. Patent Office.

Diazodinitrophenol has an ignition temperature of approximately 200°C and will ignite in flight only when the stagnation temperature exceeds this value. No special precaution need be taken to prevent preignition since environmental temperatures rarely exceed 74°C.

The failure to achieve proper functioning of the smoke composition in this application was the result of inability to recover ballistic rounds to determine the cause of puff-type smoke emission instead of the desired streaming. The use of wind tunnel facilities would have eliminated this problem and would also have made possible the correlation of variations in smoke composition consolidation techniques; number, size and positioning of vent holes; and desired streaming effects. Without such facilities, it can only be hypothesized that the puff-type smoke emission may have been caused by crumbling of the smoke cone on setback, followed by ignition and very rapid burning of the loose smoke composition.

RECOMMENDATION

It is recommended that chemical nose fuzes that are activated by aerodynamic heating be considered, where feasible, as replacements for the expensive, complicated mechanical fuzes currently used in artillery ammunition where nose functioning characteristics are required.

EXPERIMENTAL PROCEDURES

Materials

1 methylaminoanthraquinone	PA-PD-382, General Dyestuff Company, Division of General Aniline and Film Corporation
Thiourea (120 microns)	Catalog No. T-101, Fisher Scientific Company
Potassium chlorate (17 microns)	Merck Chemical Company
Vinyl alcohol acetate resin	MA 28-18, Palmer Products, Incorporated
Diazodinitrophenol	Hercules Powder Company
Titanium tetrachloride	Fisher Scientific Company
Sugar (confectionary, 11 microns)	National Sugar Refining Company

Blending and Loading Procedures

The smoke compositions were blended in accordance with SOP-PC-5, "SOP for Preparation of Dry Pyrotechnic Mixes Using the Abbe' Ball Mill."

The tip assemblies were loaded in accordance with SOP-PC-44, "SOP for the Loading of the Windshield Tip Assembly (Designs I and II) Utilizing the Kent Pneumatic Press DP-33508."

The nose cones were loaded in accordance with SOP-PC-8, "SOP for 4-Ton Dennison Multi-Press."

Testing

The methods for static testing the smoke compositions are described in the body of the report. Ballistic testing methods and a discussion of results and recommendations will be found in References 1 and 2.

REFERENCES

1. Erwin, T., "Development of Smoke Tracer for APDS Shot (U)," Aberdeen Proving Ground Report No. DPS-483, March 1962. Confidential Report

2. McDonald, R., "Feasibility [illegible] Tracer for APDS Shot (U)," Aberdeen Proving Ground Rep[illegible] DPS-327. Confidential Report

TABLE 1

Ignition temperatures and burning rates of igniter and smoke compositions used for a windshield tracer system

	M1A1 Squib	Diazodinitro-phenol (DDNP)	SR39A	SR66A	SR116A
Composition, %					
1-methylaminoanthraquinone	–	–	50	52	40
Potassium perchlorate, 17-24 microns	60	–	30	36	20
Sugar, 11 microns	–	–	–	11	19
Thiourea, 120 microns	–	–	20	–	–
Vinyl alcohol acetate resin	–	–	1	1	1
Diazodinitrophenol	20	100	–	–	–
Nitrostarch	5	–	–	–	–
Charcoal	15	–	–	–	–
Burning Rate, seconds/inch	–	–	8.2	58.0	23.7
Ignition Temperature, °C					
DTA (15°/min heating rate)	–	–	135	175	–
1-sec value	326	200	225	310	–
5-sec value	–	185	195	255	–

TABLE 2

Ballistic test results for windshield tracer system

Tip Radius, Design I, inches	Orifice in Tip of Cone, inches	Initiator Composition	Smoke Composition*	Time to Ignition, sec	Remarks Remarks
0.100	0.020	15 mg M1A1 70 mg SR39A	SR39A	0.1	Ignition occurred. Puff of smoke. No trailing.
0.100	0.020	15 mg M1A1 70 mg SR39A	SR39A	0.1	Ignition occurred. Puff of smoke. No trailing.
0.050	0.020	15 mg M1A1 70 mg SR39A	SR39A	0.1	Ignition occurred. Puff of smoke. No trailing.
0.050	0.020	15 mg M1A1 70 mg SR39A	SR39A	0.1	Ignition occurred. Puff of smoke. No trailing
0.100	0.020	15 mg DDNP 70 mg SR39A	SR39A	0.1	Ignition occurred. Puff of smoke. No trailing.
0.100	0.020	15 mg DDNP 70 mg SR39A	SR39A	0.1	Ignition occurred. Puff of smoke. No trailing.
0.100	0.020	15 mg DDNP 70 mg SR39A	SR39A	0.1	Ignition occurred. Puff of smoke. No trailing.

*Molded in paper cones.

TABLE 3

Static tests with design I, II, and III windshield tip assemblies

Design	Radius of Tip, inches	Construction of Tip	Initiator Composition	Remarks
I	0.10	Copper plug in steel housing	15 mg M1A1 70 mg SR39A	Plug was blown out
II	0.05	Copper	15 mg M1A1 70 mg SR39A	Withstood explosive forces
III	0.10	Copper	15 mg M1A1 70 mg SR39A	Withstood explosive forces
III	0.10	Copper	15 mg DDNP 70 mg SR39A	Withstood explosive forces

TABLE 4

Static test results SR39A, 66A, and 116A in the windshield tracer system*

Composition	Orifice, inches**	Burning Time, sec	Remarks
SR39A	0.100	3.5	Good streaming of red smoke
SR39A	0.100	6.0	Good streaming of red smoke. Detonated at end
SR39A	0.080	Too fast to measure	Detonated
SR39A	0.060	Too fast to measure	Detonated
SR66A	0.060	85	Good stream of dense scarlet smoke
SR66A	0.080	60	Good stream of scarlet smoke
SR66A	0.080	6	Good smoke. Burned fast and detonated
SR66A	0.080	90	Good stream of scarlet smoke
SR66A	0.100	62	Good stream of scarlet smoke
SR116A	0.100	50	Good stream of scarlet smoke

*The smoke composition was ignited by a strand of benite inserted through an orifice. All compositions were poured from a slurry into a windshield cone.

**Two holes drilled into the apex at 180° from each other.

TABLE 5

Ballistic test results in windshield tracer system

Round No.	Radius of Tip, Design III, inches	Orifice Openings, inches	Initiator Composition	Smoke Composition	Time to Ignition, sec	Remarks
1	0.100	0.060	15 mg DDNP 70 mg SR39A	5 g SR39A 8 g SR66A	0.1	Very light trail. No puff of smoke
2	0.100	0.060	15 mg DDNP 70 mg SR39A	5 g SR29A 8 g SR66A	0.1	Very faint white trail
3	0.100	0.060	15 mg DDNP 70 mg SR39A	5 g SR39A 8 g SR66A	0.1	Trailed all the way. Smoke did not persist
4	0.100	0.060	15 mg DDNP 70 mg SR39A	13 g SR116A	0.1	Very faint trail
5	0.100	0.060	15 mg DDNP 70 mg SR39A	13 g SR116A	0.1	Initial puff. No trail

TABLE 6

Ignition temperature tests with SR66A smoke composition in the windshield loaded tracer system*

Radius of Tip of Round, inches	Initiator Composition	Hole Configuration in Windshield Location/Number/Size, in.			Temperature of Tip of Round Upon Ignition, °C	Temperature Within Round, °C	Burning Time, sec	Remarks
0.1	None	Apex Base	2 3	0.080 0.100	330	75	20	Good streaming from all holes
0.1	70 mg SR39A	Apex Base	2 3	0.060 0.060	210	110	12	Good smoke followed by detonation
0.1	15 mg DDNP 70 mg SR39A	Apex Base	2 3	0.100 0.060	360	53	<2	Burned erratically. Gave red cloud puff with poor streaming

*Smoke puddled directly into round.

TABLE 7

Burning characteristics of windshield tracer systems*

Hole Configuration in Windshield Location/Number/Size, in.			Composition in Tip Assembly	Block Temperature, °C	Temperature of Smoke Composition Upon Ignition of DDNP, °C	Time to Ignition, sec	Burning Time, sec	Remarks
WITH SR39A SMCKE COMPOSITION								
Apex Base	2 3	0.080 0.100	15 mg DDNP 70 mg SR39A	602	415	42	40	Smoke streamed from holes in apex
Apex Base	2 3	0.060 0.060	85 mg SR39A	636	438	47	39	Smoke streamed from only one hole in apex
Apex Base	2 3	0.100 0.060	15 mg DDNP 70 mg SR39A	624	414	22	37	Good smoke stream from apex
Apex Base	2 None	0.100	35 mg DDNP	662	–	65	20	DDNP did not blow tip apart. Slight flaming did not alter good smoke
Apex	2	0.100	55 mg DDNP	675	--	40	20	DDNP blew tip apart. Good smoke but some flaming
WITH SR66A SMOKE COMPOSITION								
Apex Base	2 3	0.080 0.100	15 mg DDNP 70 mg SR39A	625	300	62	67	Good smoke stream
Apex Base	2 3	0.060 0.060	85 mg SR39A	625	390	52	120	Streaming from one hole only
Apex Base	2 3	0.080 0.060	15 mg DDNP 70 mg SR39A	720	416	18	127	Good smoke stream

*All smokes were pressed directly into rounds at 3 tons dead load.

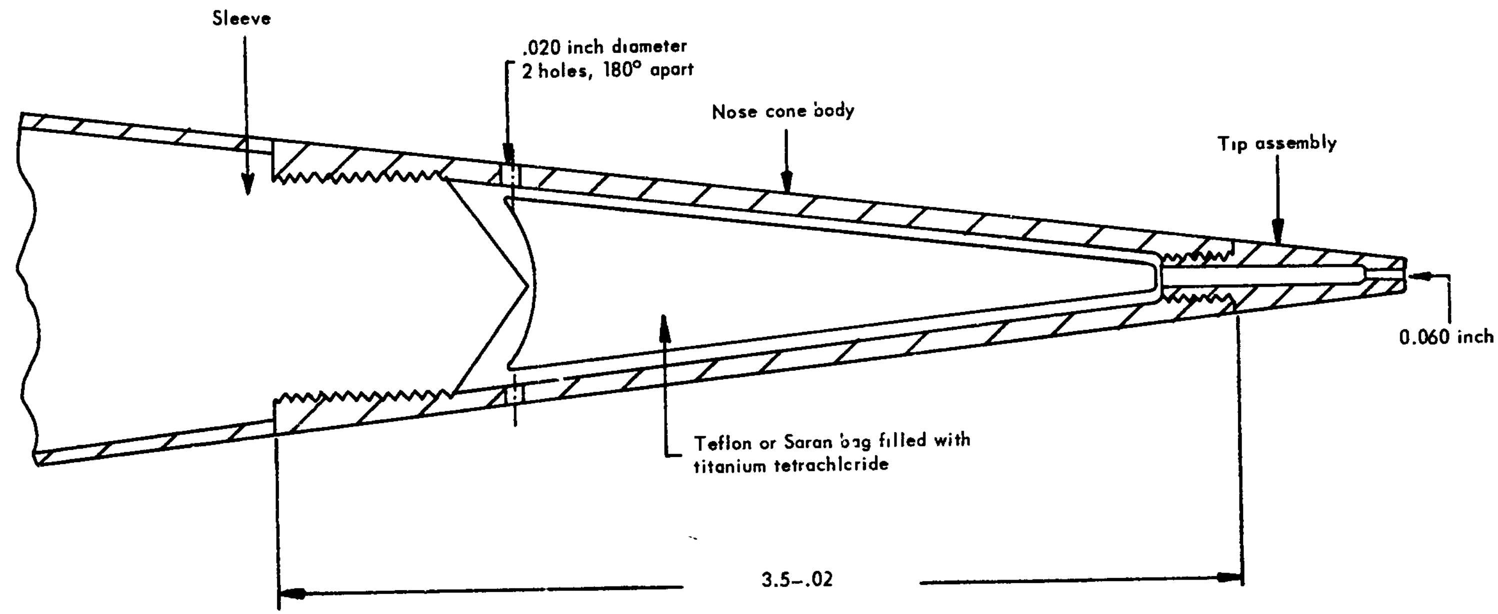

Fig 1 Diagram of the windshield sleeve, nose cone body, and tip assembly

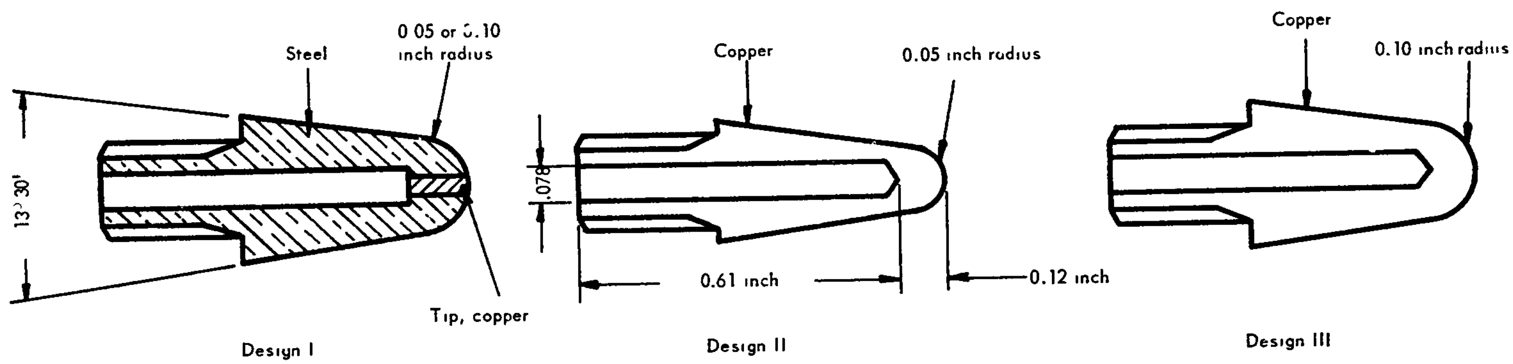

Fig 2 Tip assemblies

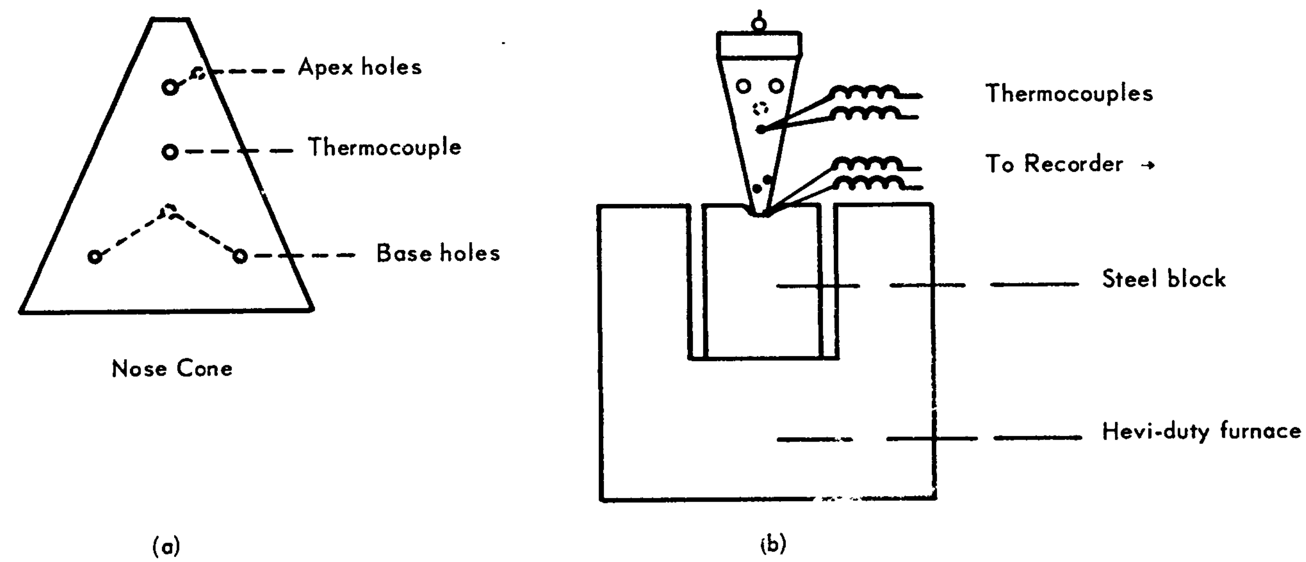

Fig 3 Ignition temperature apparatus

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13 ABSTRACT

A feasibility study of a smoke or vapor stream system to function in the nose cone of a fin-stabilized round was conducted. The conventional base-located system could not be used because (a) the round contained a discarding sabot mechanism, and (b) the vibration, jolt, and dust following the discharge of the large vehicle-mounted gun would cause the gunner to momentarily lose sight of the missile. Hence, a persistent trail observable by daylight was needed.

Titanium tetrachloride was tried because, on exposure to air, it forms dense white clouds of titanium hydroxide. However, the corrosive properties of this material made it difficult to package. Since calculations indicated that nose temperatures exceeding 300°C would be attained during projectile flight, a new approach using a heat-sensitive initiator was formulated. Diazodinitrophenol (DDNP), which ignites after 0.25 second of flight (200°C) was pressed into the nose cone tip assembly. A conically shaped red smoke composition was inserted directly behind the DDNP. Two holes drilled near the apex of the cone body allowed the generated smoke to escape. This approach worked satisfactorily in static tests. In ballistic tests, however, the smoke composition was ejected as a puff of red smoke with no streaming.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Smoke tracer						
Armor-piercing round						
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Fin-stabilized round						
Diazodinitrophenol						
Titanium hydroxide						
Chemical nose fuze						
APDS shot						
Aerodynamic heat transfer						
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